

## Academic/industry innovations for sustainable building design and refurbishment

Dimitrijevic, Branka

*Published in:*  
Proceedings of the International Conference on Management and Innovation for a Sustainable Built Environment (MISBE2011)

*Publication date:*  
2011

*Document Version*  
Author accepted manuscript

[Link to publication in ResearchOnline](#)

*Citation for published version (Harvard):*  
Dimitrijevic, B 2011, Academic/industry innovations for sustainable building design and refurbishment. in JWF Wamelink, RP Geraedts & L Volker (eds), *Proceedings of the International Conference on Management and Innovation for a Sustainable Built Environment (MISBE2011)*. Delft University of Technology, Delft, Netherlands. <<http://www.misbe2011.nl/>>

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## **ACADEMIC/INDUSTRY INNOVATIONS FOR SUSTAINABLE BUILDING DESIGN AND REFURBISHMENT**

**BRANKA DIMITRIJEVIC**

Glasgow Caledonian University  
70 Cowcaddens Road, Glasgow G4 0BA, United Kingdom  
Branka.Dimitrijevic@gcu.ac.uk

### **Abstract**

*Development and efficient dissemination of innovations for sustainable building design and refurbishment are crucial for the competitiveness of companies operating in the construction sector which faces pressure to reduce levels of carbon emissions from existing and new buildings to zero. An overwhelming majority of companies operating in the construction sector in Scotland are small to medium size enterprises (SMEs) who do not have sufficient resources in the current economic downturn to undertake research in building design, products and processes that will make buildings more sustainable. A joint project of seven Scottish universities has been initiated to support collaboration with small to medium sized enterprises in developing and disseminating innovation for sustainable building design and refurbishment. The project concept and methods used for efficient dissemination of the project outputs to SMEs across Scotland are explained. An analysis of the outputs of completed feasibility studies and the provision of academic consultancy through the project indicates the range of problems tackled as well as trends in the development and use of innovations for a more sustainable built environment in Scotland.*

**Keywords:** Construction innovations, academia, SMEs

### **INTRODUCTION**

The importance of the sustainable built environment for sustainable development of Scotland was emphasised in the Scottish Government's strategy for sustainable development *Choosing Our Future* (2005) and *The Government Economic Strategy* (2007). One of the objectives of the *Scottish Construction Industry Plan 2007-2012* (Scottish Construction Forum, 2007) is to increase good practice in sustainability by sharing best practice and innovation. The Scottish Government's *Policy on Architecture for Scotland* (2006) encourages the recognition and adaptive re-use of Scotland's historic buildings rather than their replacement to meet the objectives of sustainable development of the built environment. *Climate Change Adaptation by Design* (Shaw et al, 2007) and *Sustainable Housing Design for Scotland* (Stevenson and Williams, 2007) point out that it is existing stock which can potentially make the most effective contribution to meeting sustainability objectives and reducing carbon.

The Scottish Government aims to reduce carbon emissions in Scotland by 80% by 2050 as outlined in the *Climate Change (Scotland) Act 2009*. *A Low Carbon Building Standards Strategy for Scotland – Sullivan Report 2007* recommends future revisions to the CO<sub>2</sub> target reductions within the Building Regulations as follows: 2010 – CO<sub>2</sub> savings of 30% more than 2007 building standards; 2013 – CO<sub>2</sub> savings of 60% more than 2007 building standards; 2016/17 – net zero carbon buildings (i.e. space/water heating, lighting & ventilation).

The above targets for carbon reduction cannot be achieved without innovations. The challenge is increased by the risk-averse attitudes of building clients, contractors and building control officers towards innovations. The WWF Scotland (2008) report *Carbon Countdown for Homes: How to make Scotland's existing homes low carbon* points out that sufficient numbers of experienced and knowledgeable building control officers and local authority planners are needed to ensure there are no bottlenecks in obtaining permissions for improvements.

The consultations with the industry organised by the Scottish Construction Centre (Scottish Construction Centre, 2008), the conference *Lifting Barriers to the Application of Construction Innovations in Scotland*, held at Glasgow Caledonian University on 25 March 2009 (The Centre for the Built Environment, 2009), and the report on *Developing Scotland's low carbon built environment* undertaken by BRE Scotland on behalf of Scottish Enterprise (Kelly, 2010), highlighted that the affordability of research for SMEs, the lack of tested innovative solutions and guidelines on how to apply them in practice are perceived as barriers to the adoption of innovations. This market failure within the above context of policies for creating a more sustainable built environment has been identified as a focus for the CIC Start Online project.

## **CIC START ONLINE PROJECT**

The aim of the Construction Improvement Club (CIC) Start Online project is to embed innovations for sustainable building design and refurbishment into practice. The objective is to support collaboration between academia and Scottish small to medium size enterprises (SMEs) in developing and testing innovations for sustainable building design and refurbishment. The project is led by Glasgow Caledonian University (GCU) in collaboration with Edinburgh Napier University (ENU), Glasgow School of Art (GSA), Heriot-Watt University (HWU), the Robert Gordon University (RGU), University of Edinburgh (UE) and the University of Strathclyde Glasgow (USG). The project is funded by the European Regional Development Fund and Scottish Government from 1<sup>st</sup> September 2009 until 31<sup>st</sup> August 2012.

CIC Start Online runs a quarterly competition for 50 feasibility studies (FS) and 19 academic consultancies (AC) on sustainable building design and refurbishment undertaken for the benefit of Scottish SMEs. The joint academic/industry applications are assessed and approved by an independent assessment panel whose members are representatives of the Buildings Standards Division of the Directorate for the Built Environment of Scottish Government, the Scottish Association of Building Standards Managers and energy efficiency consultants.

The outcomes of academic/industry collaboration are presented at seminars, transmitted online as webinars in real time and then made available as video recordings on demand at the project website [www.cicstart.org](http://www.cicstart.org) to the project members. Membership is free and open to everyone.

Three whole-day online thematic conferences are planned. The first one, on *Sustainable Refurbishment*, was delivered on 4<sup>th</sup> June 2010. The seven webcasts filmed in collaboration with academic partners are available free at the project website following registration. The second conference will deliver the project partners' webcasts on their research and innovation related to the *Resilience of Buildings, Neighbourhoods and Cities*. This conference will take place online

from 14<sup>th</sup> until 17<sup>th</sup> June 2011. Each webcast will be followed by an interactive discussion with their authors.

The project publishes a quarterly free online Innovation Review that includes case studies on innovation for sustainable building design, construction and refurbishment applied in practice, information on support for innovation and related research.

Online dissemination of the project outcomes has assisted in attracting membership across Scotland, the United Kingdom, and internationally. By the end of February 2011, the project has over 620 members from over 470 organisations, of which over 320 companies are Scottish SMEs. Online dissemination of the project outcomes reduces carbon emissions of the continuous professional development of the project members.

## **INNOVATIONS SUPPORTED BY CIC START ONLINE PROJECT**

The following section provides an overview of the types of innovations supported through FS or the innovations that have been further refined through AC. The overview is based on the studies completed or initiated until the end of January 2011. The approved applications can be divided into five thematic groups as presented below: Sustainable building design, Sustainable refurbishment, Post occupancy evaluation, Sustainable building materials and components, and Decision making for sustainable building design and refurbishment. The competition is open to additional potential themes for FS or AC that will address other aspects of the application of innovations for sustainable building design and refurbishment in practice.

### **Sustainable building design**

*A Hybrid Solar Thermal Mass (HSTM) System Development for the Application to Tenants First Housing Co-operative's Zero-carbon Affordable Homes*, GSA, ENU and Tenants First Housing Co-operative, Aberdeen.

The benefits of using the building foundation as the heat store over alternative, more common, wet (or phase change) thermal storage media were demonstrated. The study concluded that using the Ecocirc pump in combination with a 30 Wp PV module, the desired design condition of a relatively constant collector outlet temperature can be achieved in practice. Measurement of irradiance, and collector temperature and flow, has provided an accurate appraisal of the Solartwin collector thermal performance. It indicates that the HSTM system is able to deliver heat to, and store heat within, the thermal mass of the building foundation (Noguchi et al, 2010).

*Assessment and Application of Zero Carbon Building in Scotland*, HWU and IES Ltd, Glasgow

The study involved investigation of recently published guidelines into the definition of 'Zero carbon' by the government and a comparison with 'true' zero carbon buildings. The study uses the proposed Riccarton Ecovillage on the campus at HWU to provide the sample building used for the detailed analysis and assessment parts of the study. HWU and IES worked together using IES's Virtual Environment software to perform predictions of carbon emissions. The detailed calculations consider a range of currently available building technologies, and systems that could be used either in isolation, or in conjunction with one another. The analyses are intended to demonstrate the differences between current building standards and the improvements that will be needed in future both to meet the published regulatory guidelines and also to provide a

comparison with true zero carbon using representative domestic Scottish buildings as the basis for the analysis. The report aims to show what renewable technologies need to be employed in order to meet Zero Carbon – using both dynamic simulation methods and Building Regulations SAP software meeting the Scottish Technical Standards Section 6 requirements (Roaf and McEwan, 2010).

*Tarryholme Sustainable Housing Project*, USG and Assist Design, Glasgow

Assist Design is currently engaged in a sustainable housing development project Tarryholme Eco-House in Irvine in collaboration with the Irvine Housing Association and Irvine Bay Regeneration Company. The project aims to attain a higher level of sustainability than those promoted by existing assessment protocols and be reflective of contextual realities in Irvine. The study aims to demonstrate that it is possible to build an affordable, organic Eco dwelling that can optimise the conflicting demands of energy efficiency and good indoor air quality in the context that the UK has the highest prevalence of asthma in 13-14 year olds and that the last 25 years has seen the incidence of asthma episodes increase four-fold in adults and six-fold in children. The study will include the detailed design of a two-bedroom, semi-detached property including drawings, specifications, whole life cost and carbon analysis. Direct comparison with an affordable house designed to the 2010 Scottish Building Standards will also be provided (Howieson and McCafferty, 2010).

*Energy Impact of different strategies of integrating PV/Thermal heat transfer*, GSA and Robert Ryan Timber Engineering Limited, Saltcoats

Robert Ryan Timber Engineering Limited is developing design ideas and solutions towards the construction of two net 'zero-energy' healthy housing prototypes in North Ayrshire which aim to surpass the energy usage profile of zero-carbon counterparts being recognised by the UK Government. Extensive studies have been conducted on the design optimisation of photovoltaic thermal (PV/T). However, the energy impact of a PV/Thermal Heat Recovery unit integrated into housing for space heating is barely conceived or examined in today's homebuilding industry. The goal of this feasibility study is to assess the most effective strategies of integrating PV/T Heat Recovery (PV/T HR) system in Scottish 'zero-energy' housing in the context of energy, economic and life cycle performance. It will be conducted through scale model experiments to test different installation (PV/T HR architectural integration) scenarios and the performance with aim of applying the PV/T HR system to the two zero-energy demonstration homes (Masau and Noguchi, 2010).

*Enkelt Simple Living* GSA and Ballyconnelly Construction Ltd, Wemyss Bay

The purpose of study is to scope out the next stage of improvements to the Enkelt house model developed by Ballyconnelly Construction Ltd. This will include identification of minimum standards as well as improved U-values with increased insulation using a 180mm SIP panel; improved window and door specification balancing the brief to maintain cost level at typical housing construction cost; improved efficiency of the MVHR unit with e.g. integrated ASHP and Hot Water Cylinder, reviewing the potential to remove the heating system; potential for integrated renewable systems such as solar hot water, PV and heat pumps and their impact to reduce future running costs and CO<sub>2</sub> emissions; assessment of the responsible sourcing of materials reviewing any opportunity for improvement; assessment of the Enkelt system against recognised criteria e.g. EcoHomes, Code for Sustainable Homes, and appraisal of potential

improvement against these criteria; and a review of potential for a prefabricated modular version of the Enkelt home to improve construction time and build quality (Sharpe and Stewart, 2010).

*Independent verification of a climate based worldwide building energy index*, GCU and IES Ltd, Glasgow

IES Ltd has prototyped a set of energy indices that can be used to assess, classify and compare any worldwide climate (weather data or extrapolated climate change data) for the purposes of understanding climate and for the use in sustainable building design. The indices are intended as rapid and interactive holistic design tools applicable to any building type, with any design strategy, in any location worldwide and for the simple quantification of the impact of climate change on building energy progressively over a sustainable building's lifecycle. The basis of the indices is the fact that climate underlies building energy use and it is therefore possible to compare designs relative to climate, visualise where design emphasis needs to be placed and directly and interactively track the effect of design strategies. The index is applicable to both the design and operational phases of buildings and is directly usable by building professionals without the need for specialist energy knowledge i.e. architects, quantity surveyors, students, etc. The SME was in need of an independent peer review and detailed verification to prove the prototyped index performs successfully. With this need in mind the academic partner carried out a review of the Climate Energy Index and the Building Energy Index developed by the SME partner with the aim of verifying their scientific soundness and ease of applicability. The following tasks were performed: a peer review of the physics and implementation of the Index, an extensive series of tests to confirm the validity of the Index, and a series of robustness tests (Kumar and Emmanuel, 2010).

### **Sustainable refurbishment**

*Tenement Flat Carbon Reduction Shopping List*, USG and Holmes Partnership, Glasgow

The study aimed to provide typical Glasgow sandstone tenement flat dwellers with a guide as to the most suitable carbon reduction measures to apply to their dwelling. In particular, it was intended to provide a cost per tonne of carbon dioxide saved comparison to demonstrate value for money for various retrofit options. A particular tenement flat was selected and surveyed. The dimensions and conditions were passed to ESRU who prepared a dynamic thermal model. Various retrofit options were agreed and applied to the model and the outcomes recorded in terms of tonnes of carbon dioxide emissions saved. Doig and Smith (Cost Consultants) prepared costs for all the retrofit options allowing the cost-per-tonne saved to be calculated (Cockroft et al, 2010).

*Upgrade Strategy Development for Garrioch Residents Association*, USG and Collective Architecture, Glasgow

The study has defined and demonstrated a process for assessing and communicating the energy upgrade options to a residents association, landlord or housing association. The first process step is a meeting with the client to explain the project and get their inputs on the current issues with the building and the range of upgrades of most interest. Following this consultation process the current building performance is established through a physical survey, air-tightness testing, thermography and smoke analysis in representative dwellings. The appropriate upgrade options and best practice examples for the building type are then researched and a reference database created. The carbon and energy performance of a representative sample of the existing dwellings

is then modelled; and the carbon, cost and energy impact of a range of upgrade options quantified. Based on best practice and modelling results some recommendations are provided. A customised version of the modelling tools is made available to the residents association and training offered to allow them to assess further upgrade options on an ongoing basis. The customised tools are similarly available as the starting point for future similar projects. A report of the outcomes of the work is prepared and presented to the clients allowing them to gain understanding. In this case the process was applied to the quadrangle of traditional red sandstone tenement flats in the west end of Glasgow represented by Garrioch Residents Association. As there are many similar properties in Scotland requiring similar upgrades, work undertaken in this study can be utilised elsewhere. However, the process is not restricted to these similar properties; it can also be applied to other dwelling types (Touhy et al, 2010).

*Solar-Wall systems for domestic heating: an affordable solution for fuel poverty*, HWU, Changeworks Resources For Life Ltd and Ormandy Ltd, Edinburgh

The aim was to test a number of key variables of a solar wall heating system currently under development, to maximise solar heat collection in the context of Scottish weather and heavy buildings built with solid walls (pre-1919 buildings account for 20% of the housing stock in Scotland). The study quantified the thermal effect of internal solid walls used as thermal storage for solar heat in tenement flats for all-day usage, optimised the device to maximise heat exchange between the wall and hot water from the solar panel, provided a modelling tool to enable a Solar Warm Wall system to be designed to suit individual buildings (either new or retrofit), and estimated costs of system implementation. In addition, this study analysed solar availability, heating demand and domestic water supply for two typical dwellings based on two reliable methods: a) a purposely developed dynamic thermal model, and b) data collected in previous studies carried by Changeworks. The tests were carried out using two methods: Computational Fluid Dynamics (CFD) and laboratory simulation. Developing the CFD model was one of the major objectives of this feasibility study. The lab tests were conducted to collect data to validate the CFD model (Wang and Roaf, 2010).

*Synergy of Fabric and Energy conservation in older historic properties*, ENU and The Morrison Partnership, Edinburgh

The Morrison Partnership (Architects) have a private client who wishes to convert and extend a 19th century traditional built two storey mansion house in Alyth, Blairgowrie, Scotland. The proposal is to convert the former hospital to a home. An energy efficient heating system for both space and hot water was proposed, which is not only sustainable but respects the behaviour and appearance of the existing historic building fabric. The study will identify appropriate actions in achieving minimal fabric intervention for maximum energy conservation in traditional buildings with specific reference to solid stone/ lath & plaster wall construction typical of the 19th century in Scotland. The project will aim to address: 1. Environmental issues by seeking methods of reducing CO<sub>2</sub> emissions and improving energy conservation and management in older, difficult to heat, stone built properties; 2. Social issues by improving health as a result of improved and balanced indoor air and heating quality; 3. Economic issues by considering whole-life energy costs in large domestic, difficult to heat, buildings in Scotland. The proposal will aim to: 1. Establish a detailed energy assessment process for the building study type that could be used in other similar projects; 2. Identify future research and improvement work in this area to develop and market an energy management process for this building type (Currie and Purdie, 2010).

## **Post occupancy evaluation**

*Development of Post Occupancy Evaluation for evaluation of innovative low carbon socialhousing projects*, GSA and John Gilbert Architects Ltd, Glasgow

The study includes a monitoring programme over a 2 – 4 week period of time measuring performance in terms of temperature, humidity, air quality, general and specific energy consumption. This is supplemented by interview, questionnaire, observation and spot measurement to determine occupancy regimes, patterns of use and consumption, users understanding of systems and controls. The second stage comprises a limited number of pilot programmes to test the methodology and data capture systems. The long term aim is to enable participating housing associations to understand how the performance of their housing is in comparison to other projects, what changes they may consider making to future projects as well as addressing issues in existing projects. It will also help in the setting of realistic energy targets so that those setting the targets have a real understanding of the consequences and achievability of certain energy targets. The eventual goal is to provide a much more accurate feedback loop on performance, problem detection, remediation and avoidance, and improved design and specification (Sharpe and Gilbert, 2010).

*Embedding simplified post occupancy evaluation in design process*, USG and Page and Park Architects, Glasgow

The team studied: 1. information relating to existing POE methods; 2. current benchmarks to determine industry best practice and compare appropriate figures against Page & Park attainments; 3. various existing questionnaires in order to devise a simple questionnaire that clients would regard as user-friendly; and 4. the range of formats in which clients/companies receive energy data so that a meaningful POE process could be devised that would cope with a wide range of data. It was decided that the most effective way to deliver a simplified POE process, to complement the existing work practices of Page & Park, was to design and trial a software tool, named POET (for Post Occupancy Evaluation Tool). This tool was developed over the period of the project and underwent a number of revisions to deal with issues relating to compatibility with Page & Park hardware, work practices and application expectations (Clarke et al, 2010).

*In-service testing of a prototype dwellings in relation to passive versus active ventilation strategies and assessment of air quality and comfort balance with fuel poverty avoidance*, USG and Assist Design, Glasgow

Primary research outcomes will include construction process monitoring and post occupancy evaluation. It is proposed that a dwelling with low energy characteristics can be designed to be significantly faster and easier to construct making both time and skilled labour savings that would considerably impact the potential cost of achieving greater than 60% CO<sub>2</sub> reductions. Construction process monitoring of the prototype low energy house will allow quantifying such savings and making direct comparison with an affordable housing designed and constructed to the 2010 Scottish Building Standards that meets 30% CO<sub>2</sub> reduction commitment. It is further proposed that such a dwelling should address indoor air quality and public health. Post occupancy evaluation research outcomes will be realised within 12-month monitoring period (Howieson and McCafferty, 2010).



*9-11 Gilmour's close – comparing the theoretical performance of a suite of sustainable installations in the building against actual performance and user experience*, GSA and Assist Architects, Edinburgh

9-11 Gilmour's Close is a low-carbon refurbishment project for Hillcrest Housing Association, located in Edinburgh's World Heritage Site. The project addressed the difficult task of refurbishing an existing listed building to minimize CO<sub>2</sub> emissions and dependency on non-renewable energy sources. The project aims to gather data to compare the theoretical performance with actual performance. The context for this is the increasing need to develop design and technologies for all newly built homes to ensure that they would be carbon-neutral by 2016. Whilst predictions can be made about performance at design stages, there is very little evidence being collected about how these buildings perform in use. This gap in knowledge must be addressed if effective designs and technologies are to meet these rigorous standards (Sharpe and Jack, 2010).

*Post Occupancy Evaluation of Municipal Terrace, Dumfries*, GSA and Dumfries & Galloway Housing Partnership (DGHP), Dumfries

The Municipal Terrace in Dumfries was built in 1913 to house the "working classes". The block consists of eight one-bedroom workman dwellings that have cavity walls, which is unusual for the built age, with 9" outer leaf, 2" cavity and a 4½" inner leaf. The property had two large rooms and a rear scullery which was built in solid 9" brickwork (area converted into kitchen/bathroom 1962-3). DHGP developed and incorporated ways of improving four of eight homes above existing Building Regulations levels and along the ideas, principals and standards of ecological building design and refurbishment (including Passivhaus). In order to test the effectiveness of these measures, this consultancy will undertake a post occupancy evaluation to examine the performance of the dwellings (Sharpe and Trant, 2010).

### **Sustainable building materials and components**

*Developing Homegrown Natural Fibre Insulation Products*, GCU and Kraft Architecture, Glasgow

Kraft Architecture has been working on in-house research into the processes and manufacturing of natural fibre products using home-grown & waste fibres. Having identified prototyping facilities, waste material suppliers and carried out market research into demand, they are now at a stage where they wish to prototype the product and have the products undergo testing. This project is focused primarily on the use the climatic chamber facility in GCU's Centre for Research on Indoor Climate and Health to test the thermal performance, vapour diffusion, resistance co-efficient of prototype natural fibre insulation product(s) consisting of various recycled waste textile and cellulose materials (Baker and Newlands, 2010).

*Novel Solar Thermal Collector Design*, HWU and AES Ltd, Forres

The primary objective was to improve the basic design of the AES solar thermal collector; to make it more efficient, lighter and more robust and generally a more fit for purpose and greener product. The intention is to provide an improved collector to market at a competitive price relative to the current one. Taking into account that the solar gains and heat losses are linked to conditions of operation and design of the collector, it was necessary to focus on analyzing the mechanism of energy gains and losses from the collector, such as type of material cover, material housing, insulation material properties, surface area, weather conditions, inlet temperature water,

ambient temperature, mass flow rate, position of collector, dimensions, gross area to absorber area ratio, absorber material and best thickness, and collector tilt angle. Four sample units were manufactured by AES and supplied to HWU for thermal performance testing (Roaf and MacLennan, 2010).

### **Decision making for sustainable building design and refurbishment**

*An Investigation of the Adoption of Low-Carbon Technologies by Scottish Housing Associations*, RGU and Anderson, Bell and Christie Architects, Glasgow

A feasibility study was proposed as a means of investigating the decision making of housing associations (HAs) with regard to the adoption of low carbon technologies. The starting point for the study was a consideration of what impact incentivisation schemes (in this case particularly feed-in tariffs) had on the adoption of low carbon technologies. The study developed further, in that it added an objective to assess the feasibility of producing a unified business process (UBP) focused on aiding individual HAs when deciding which low carbon technologies (LCTs) are appropriate to them. The study involved two housing associations that had both considered the adoption of innovative sustainability technologies, but ultimately made different investment (in the form of “purchasing” sustainable technologies) decisions. Within the study, interview and document analysis methods were used to determine both the culture (in terms of propensity to innovate) and any filters that had strong or weak impact on the decision making of the respective housing associations (Moore et al, 2010).

## **DISCUSSION**

The launch of the CIC Start Online project at the seven universities involved in the project in October and November 2009 provided opportunities to advise the industry on funding available to Scottish SMEs for collaboration with academia in developing innovations for sustainable building design and refurbishment. SMEs’ requests for assistance are submitted online as a brief description of a problem that they wish to tackle and forwarded to the project partners. Sometimes, the assistance is provided jointly by the academics from different partners’ institutions according to the expertise required and available for addressing different aspects of an innovation.

The overview of the studies approved to date indicates that there is an interest in tackling innovations both for existing and new buildings, and for assessing their true impact through post occupancy evaluation. The studies have also enabled SMEs to access laboratories at the participating universities to test innovative building products and technologies. How building clients make decisions in relation to the incentives to reduce the carbon emissions of buildings was the theme of one academic consultancy that will provide an insight not only for the architects who initiated this research, but also for the wider professional audience when the research outcomes are presented at a forthcoming seminar and webinar.

The scope of the approved studies includes not only the environmental impact of buildings such as the reduction of carbon emissions and the use of renewable energy and building resources, but, in many cases, the social and economic impacts by tackling fuel poverty, indoor air quality and whole life costs for building occupants. As only the innovations that simultaneously address environmental, social and economic impact could contribute to a more sustainable built

environment; this was one of the main conditions of the competition. As a consequence, interdisciplinary collaboration of researchers from different departments at the partners' institutions and sometimes with external consultants has been initiated.

Feasibility studies and academic consultancies have developed new knowledge regarding the technologies for generating energy from renewable resources and building materials made of recycled or renewable natural resources. They have also contributed to a better understanding of how new technologies can be integrated in existing and new buildings to reduce carbon emissions and fuel poverty. Other studies have refined some existing software tools for building modelling, or indicated the limitations in some existing assessment tools that should be considered when using them to estimate building performance, or used the tools to indicate improvements required in traditional building types to achieve zero-carbon standards. Most studies focused on real building projects, either recently completed as exemplars of sustainable design or refurbishment that need to be verified through monitoring or to suggest further improvements to achieve zero-carbon standards. Due attention was given to existing building stock by consulting building occupants on how buildings are used, applying innovative methods for assessing building performance, recommending and estimating costs of potential improvements, and providing guidelines to the building owners on how to undertake future assessments and improvements.

As the studies have been initiated by the industry, they indicate the range of issues that the industry faces in its efforts to create a more sustainable built environment, a range which will probably be extended in the future applications for feasibility studies and academic consultancy through the CIC Start Online project. The majority of studies focused on the Scottish environmental, social and economic context regarding the need for more sustainable existing and new built environment, thus assisting in solving local problems. However, some studies have tackled more generic innovations in sustainable building design and refurbishment that can be applied internationally. The results of both approaches assist in increasing the competitiveness of SMEs which have benefited from their collaboration with academia through the CIC Start Online project, and of the project members to whom the outcomes of innovations are disseminated through seminars, webinars, online conferences and an online magazine. The project has been included in the Scottish Green List 2010 as one of the top twenty projects that contribute to a more sustainable development of Scotland.

Webinars are increasingly used for the dissemination of knowledge on sustainable building design and refurbishment across the world, e.g. by U.S. Green Building Council (USGBC Webinars, 2011), American Society of Civil Engineers (ASCE, 2011), ArchDaily (ArchDaily, 2011) and Mechanical Contractors Association of America (MCAA, 2011). In comparison to the webinars provided by the above organisations, other professional associations or a range of consultancies and publishers, the CIC Start Online webinars disseminate the outcomes of academic/industry collaboration in developing and testing innovations for sustainable building design and refurbishment in Scotland's economic, social and environmental context. The collaboration between the seven Scottish universities and local construction sector enterprises accelerates the capacity building and increases the competitiveness of the local industry to apply innovations in practice, which is the project aim.

## CONCLUSIONS

As the academic/industry collaboration through the CIC Start Online project has contributed to the development of a range of innovations for sustainable building design and to a better understanding of how they can be applied in practice, the project partners are planning a proposal for a project extension that will eventually include more higher education institutions and link with further education institutions to support the development of skills required for creating and maintaining a sustainable built environment. In addition, stronger links are planned with local construction fora to reach all participants in the construction supply chain.

In the context of recent policies and proposals published by the Scottish Government such as *Energy Efficiency Action Plan for Scotland* (October 2010), *A Low Carbon Economic Strategy for Scotland* (November 2010) and *Low Carbon Scotland: The Draft Report on Proposals and Policies: Scotland – A Low Carbon Society* (November 2010), interdisciplinary collaboration will be further extended to reduce carbon emissions through the research and application of integrated design, refurbishment and management of the built environment that tackles energy conservation and efficiency, sustainable transport, and waste reduction, reuse, recycling and energy recovery.

## ACKNOWLEDGEMENTS

CIC Start Online is funded by European Regional Fund and Scottish Government's SEEKIT programme.

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